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COST AND PERFORMANCE REPORT ABOVEGROUND STORAGE TANKS (AST) LEAK DETECTION AND MONITORING

by
Naval Facilities Engineering Service Center
Vista Engineering Technologies, L.L.C.

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14. ABSTRACT

The Naval Facilities Engineering Service Center (NFESC), Port Hueneme, California, and its industrial partners, Vista Engineering Technologies, L.L.C., and Vista Research, Inc., have demonstrated and validated (DEM/VAL) an innovative mass-based leak detection system for aboveground storage tanks (ASTs). The *Low-Range Differential Pressure (LRDP)* system is a computer-controlled system that can reliably detect small leaks in ASTs, which range in size from 50,000 gal to ASTs with diameters of over 260 ft and containing over 10,000,000 gal of petroleum fuel. While no specific national regulatory requirements presently exist for ASTs, stringent state requirements are forcing Department of Defense (DoD) facilities to take their tanks out of service to install double bottoms and perform interstitial monitoring. With a validated, high-performance, in-tank leak-detection system for ASTs, like the LRDP, an alternative strategy is now available that is cost effective and does not necessitate taking the tank out of service. The results of the evaluation showed that the LRDP has the performance to meet the monthly monitoring and annual precision (tightness) test regulatory compliance requirements set for bulk underground storage tanks (USTs) using a test that takes less than 24 h to conduct.

This project was performed under the *Environmental Security Technology Certification Program (ESTCP)*. The objective of the ESTCP is to demonstrate and validate innovative environmental technologies that are needed to address the environmental objectives of the DoD, that are cost effective, and that will be ready for the development of commercial products and services at the completion of the DEM/VALs. All of the objectives of the project have been met, and the LRDP is ready for and is currently in commercial use.

15. SUBJECT TERMS

Environmental Security Technology Certification Program (ESTCP); leak detection; low range differential pressure (LRDP); demonstration and validation (DEM/VAL); aboveground storage tank (AST)

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ESTCP
Cost and Performance Report

Aboveground Storage Tank (AST) Leak Detection and Monitoring

ENVIRONMENTAL SECURITY
TECHNOLOGY CERTIFICATION PROGRAM

U.S. Department of Defense

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Acronyms

AST	Aboveground storage tank
CERF	Civil Engineering Research Foundation
CERL	Construction Engineering Research Laboratory (Army)
DESC	Defense Energy Support Center (DESC)
DoD	Department of Defense
EPA	Environmental Protection Agency
ESTCP	Environmental Security Technology Certification Program
EvTEC	Environmental Technology Evaluation Center
MDLR	Minimum Detectable Leak Rate
NAS	Naval Air Station
NFESC	Naval Facilities Engineering Service Center
NWGLDE	National Work Group on Leak Detection Evaluations
P_D	Probability of Detection
P_{FA}	Probability of False Alarm
P_{MD}	Probability of Missed Detect
PLC	Programmable Logic Controller
PSA	Product surface area
RTD	Resistance Temperature Device
TLR	Target Leak Rate
UST	Underground Storage Tank
VR	Volume Rate

Acknowledgments

The LRDP team would like to acknowledge and thank the fuel farm directors and their staff at the Fairchild Air Force Base, Spokane, Washington, and the Fleet Industrial Services Center (FISC), Pearl Harbor, Hawaii, for making their facilities available for the DEM/VALs of the LRDP, and for coordinating and supporting the DEM/VALs. Ken Wilcox Associates, Inc., performed the third-party evaluation of the LRDP. The work described in this report was funded through the Environmental Security Technology Certification Program (ESTCP) and is entitled, "Aboveground Storage Tank (AST) Leak Detection and Monitoring." This project is a follow-on ESTCP project that demonstrated and validated the LRDP for use in bulk underground storage tanks (USTs) and was entitled, "Validation of the Low Range Differential Pressure (LRDP) Leak Detection System for Small Leaks in Bulk Fuel Tanks." The LRDP team would like to especially thank Dr. Jeffrey Marqusee and Dr. Robert Holst for their support.

The development of this technology was made possible through the Navy's Pollution Abatement Ashore Program managed by the Naval Facilities Engineering Command and sponsored by the Environmental Protection, Safety and Occupational Health Division (N45) of the Chief of Naval Operations, the Preproduction Initiative Program, and DoD's Environmental Security Technology Certification Program. The LRDP was initially developed by NFESC and Vista Research, Inc. This work was performed by Vista Engineering Technologies, L.L.C., the Naval Facilities Engineering Service Center (NFESC), and Vista Research, Inc.

The work on this ESTCP project was performed by Vista Engineering Technologies, L.L.C., the Naval Facilities Engineering Service Center (NFESC), and Vista Research, Inc. The persons performing the work are presented below.

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1.0 Executive Summary

The Naval Facilities Engineering Service Center (NFESC), Port Hueneme, California, and its industrial partners, Vista Engineering Technologies, L.L.C., and Vista Research, Inc., have demonstrated and validated (DEM/VAL) an innovative mass-based leak detection system for aboveground storage tanks (ASTs). The *Low-Range Differential Pressure (LRDP)* system is a computer-controlled system that can reliably detect small leaks in ASTs, which range in size from 50,000 gal to ASTs with diameters of over 260 ft and containing over 10,000,000 gal of petroleum fuel. While no specific national regulatory requirements presently exist for ASTs, stringent state requirements are forcing Department of Defense (DoD) facilities to take their tanks out of service to install double bottoms and perform interstitial monitoring. With a validated, high-performance, in-tank leak-detection system for ASTs, like the LRDP, an alternative strategy is now available that is cost effective and does not necessitate taking the tank out of service. The results of the evaluation showed that the LRDP has the performance to meet the monthly monitoring and annual precision (tightness) test regulatory compliance requirements set for bulk underground storage tanks (USTs) using a test that takes less than 24 h to conduct.

This project was performed under the *Environmental Security Technology Certification Program (ESTCP)*. The objective of the ESTCP is to demonstrate and validate innovative environmental technologies that are needed to address the environmental objectives of the DoD, that are cost effective, and that will be ready for the development of commercial products and services at the completion of the DEM/VALs. All of the objectives of the project have been met, and the LRDP is ready for and is currently in commercial use. Both (1) on-line, permanently installed monitoring and testing systems and (2) tightness testing services using the LRDP can be obtained commercially through Vista Research. The results are described in the ESTCP final report and a published paper [1,2].

In a previous ESTCP project, the LRDP was demonstrated and validated for bulk USTs in a 122.5-ft-diameter bulk UST containing 2,100,000 gal of fuel at the Point Loma Fuel Terminal, San Diego, California. The LRDP used in this AST evaluation is identical to the one used in these previous bulk UST DEM/VALs, except a temperature sensor was added to the outside wall of the tank and the test protocol was changed to require that the test begin and end at night.

The LRDP system is fully automatic and is comprised of (1) an innovative in-tank level sensing unit to measure temperature-compensated level changes in the tank, (2) a temperature sensor mounted on the external wall of the tank to compensate for the thermal expansion and contract of the wall during a test, (3) a remote test controller to collect and analyze the data from a test, and (4) a host computer to initiate, report, and archive the results of a test. The electronics meet Class 1, Div. 1 standards. The in-tank sensor can be installed through a standard 8-in.-diameter opening without removing fuel from the tank. The LRDP system is compatible with the DoD Fuels Accounting System (FAS) and can be integrated with FAS to test all of the tanks in a fuel farm or a bulk storage facility.

Two AST DEM/VAL tests were conducted between September 2001 and September 2002 [3]. The objective of the first DEM/VAL was to demonstrate that the LRDP can be used to test fixed-roof ASTs with floating pans. This DEM/VAL was conducted in a 54-ft-diameter, fixed-roof tank with a floating pan at Fairchild Air Force Base between September 2001and February 2002. The results of this DEM/VAL showed that the LRDP could be used to perform accurate tests in a tank with a floating pan.

The objective of the second DEM/VAL was to determine the performance of the LRDP in an AST through a third-party evaluation following an evaluation procedure developed by the third-party evaluator that was similar to and compliant with EPA's standard test procedure for bulk USTs. The results of the evaluation are reported in terms of leak rate, probability of detection (P_D), and probability of false alarm (P_{FA}). The third-party evaluation was performed by Ken Wilcox Associates, Inc. (KWA), a nationally recognized third-party evaluator. The evaluation consisted of 24 blind tests conducted on a 164.5-ft-diameter, 6,470,000-gal bulk AST containing jet fuel (JP-8) and located at the Fleet Industrial Service Center (FISC), Pearl Harbor, Hawaii. The tests were conducted over a wide range of ambient air temperature and induced leak conditions beginning on June 19, 2002 and ending on August 29, 2002. Leaks were induced in 11 of the tests.

The results of the third-party evaluation, which are presented in this report, indicate that in a single 20-h test the LRDP-24 can detect a leak of 0.932 gal/h with a P_D of 95% and a P_{FA} of 5% in a 164.5-ft diameter tank. The performance of the LRDP-24 scales with the product surface area of the tank (i.e., the tank diameter squared) and improves as the tank diameter decreases. The third-party evaluation results indicate that the LRDP-24 can detect leaks as small as 0.2 gal/h in a single test in a 76-ft-diameter tank with a P_D = 95% and a $P_{FA} \leq$ 5%. By conducting and averaging four tests, a 0.2-gal/h leak can be detected in a 108-ft-diameter tank with the same probabilities of detection and false alarm. For monthly monitoring purposes, the LRDP-24 can detect leaks as small as 1.0 gal/h in a single test in a 170-ft-diameter tank with a P_D = 95% and a $P_{FA} \leq$ 5%. In addition to a P_{FA} = 5%, the LRDP can also be operated with P_{FA}s of 1%, 0.0016%, and $\ll$ 0.001%.

The LRDP can realize significant cost savings in three areas. First, the LRDP allows the DoD a very much less expensive alternative for meeting various regulatory requirements that now require DoD facilities to take their tanks out of service to install double bottoms and perform interstitial monitoring. Second, the LRDP is significantly cheaper to purchase, operate, and maintain than other leak detection technologies because of the low recurring cost of each test performed. It is the only mass-based system that can be used as an on-line monitoring system that can perform both monthly monitoring tests and annual precision tests. Due to the precision test capability of the LRDP, for each tank brought into compliance, the LRDP can realize cost savings over other in-tank, mass-based ATG methods and other testing services using mass-based methods by a factor of 3:1 and 11:1, respectively, over a 10-year period. Due to the high recurring costs of in-tank tracer methods, the cost savings realized by the LRDP over these methods can be well over a factor of 5:1 over a 10-year period. The payback for a permanently install LRDP is less than a year when compared to using an in-tank testing service or a tracer method. Thus, savings of up to several tens of millions of dollars can be realized for each DoD fuel storage facility. Third, in addition to the installation and operational cost savings, the LRDP has the potential to save DoD many hundred of millions of dollars in terms of clean-up and tank replacement cost avoidance.

2.0 Technology Description

The *Low Range Differential Pressure (LRDP)* system is an innovative technology that was originally developed for the reliable detection of small fuel leaks in the *bulk* underground storage tanks (USTs) that are owned or operated by the Department of Defense [4-10]. If a tank is leaking, the LRDP quantitatively measures the leak rate in gallons per hour, the quantity of regulatory interest. The LRDP is a fully automatic, mass-based system, which is easy to install and use. The LRDP system can be permanently installed in a tank and used for on-line monitoring and precision (tightness) testing. It can also be used as a portable system for periodic testing of any tank in the fuel farm. The minimum duration of a test is 20 h.

The LRDP for bulk USTs was demonstrated and validated in an ESTCP project completed in 2001 [6-8]. Under this ESTCP project, the LRDP was adapted for testing ASTs. Only two small but very important modifications were made. First, a temperature sensor was attached to the outside wall of the tank to compute the level changes associated with the thermal expansion and contraction of the wall. Second, the test was begun and ended at night (during darkness) so that the spatial variation in temperature due to direct solar heating and cooling on different parts of the tank could be minimized. Otherwise, the LRDP used in this AST evaluation is identical to the one used in the previous bulk UST evaluations.

The main source of error in testing ASTs for leaks, which was emphasized during the third-party evaluation, is produced by air temperature. The ambient diurnal temperature changes, which affect the thermal expansion and contraction of the fuel, the wall, and the instrumentation, may be 10 to 20^{o}F per day (0.42 to 0.83 ^{o}F/h), or more, for ASTs. In bulk USTs, ambient air temperature changes are not an important source of noise.

2.1 Technology Development and Application

The LRDP system is fully automatic and is comprised of (1) an innovative in-tank level sensing unit, (2) a temperature sensor mounted to the outside wall of the AST, (3) a programmable logic controller (PLC) or an embedded remote test controller to collect and analyze the data from a test, and (4) a host computer to initiate, report, and archive the results of a test. The in-tank sensor is comprised of a reference tube, which extends from the bottom of the tank to above the highest anticipated fuel level, a sealed container at the bottom of the reference tube, which houses the measurement sensors, and a valve at the bottom of the tube to allow fuel in the tank to enter the tube.

The pre-production prototype of the LRDP system for use in ASTs is shown in Figure 1. In Figure 1, the LRDP is shown being installed in the fixed-roof AST with a floating pan that was used in the first DEM/VAL. The level-measurement sensor is an off-the-shelf, industrial-grade differential pressure (DP) sensor that is located in a sealed container at the bottom of the in-tank sensing unit. Level measurements are made with a precision of 0.0002 in. Figure 1 also shows the tripod used to install the in-tank level sensing unit through an 8-in.-diameter opening at the top of the tank. A test is initiated by an operator using the host computer. The PLC (i.e., remote test controller), located in close proximity to the tank, automatically operates the LRDP system. A test report is generated upon completion of the test.

The results of a test are Pass, Fail, or Inconclusive. A volume rate (i.e., a leak rate) is reported only if the tank fails the test. An inconclusive test occurs if the data fail a data quality test, and it is recommended that the test be repeated. A number of data quality indices ("DQIs") have been developed for the LRDP. These DQIs, based on empirical data, assure the data used to compute the test result are of sufficient quality for analysis. The DQIs verify that there were no product transfers, product sampling, data acquisition problems, or unusual weather conditions during the test. The LRDP system is compatible with the DoD Fuels Accounting System (FAS) and can be integrated with FAS to test the tanks in a fuel farm or bulk storage terminal.

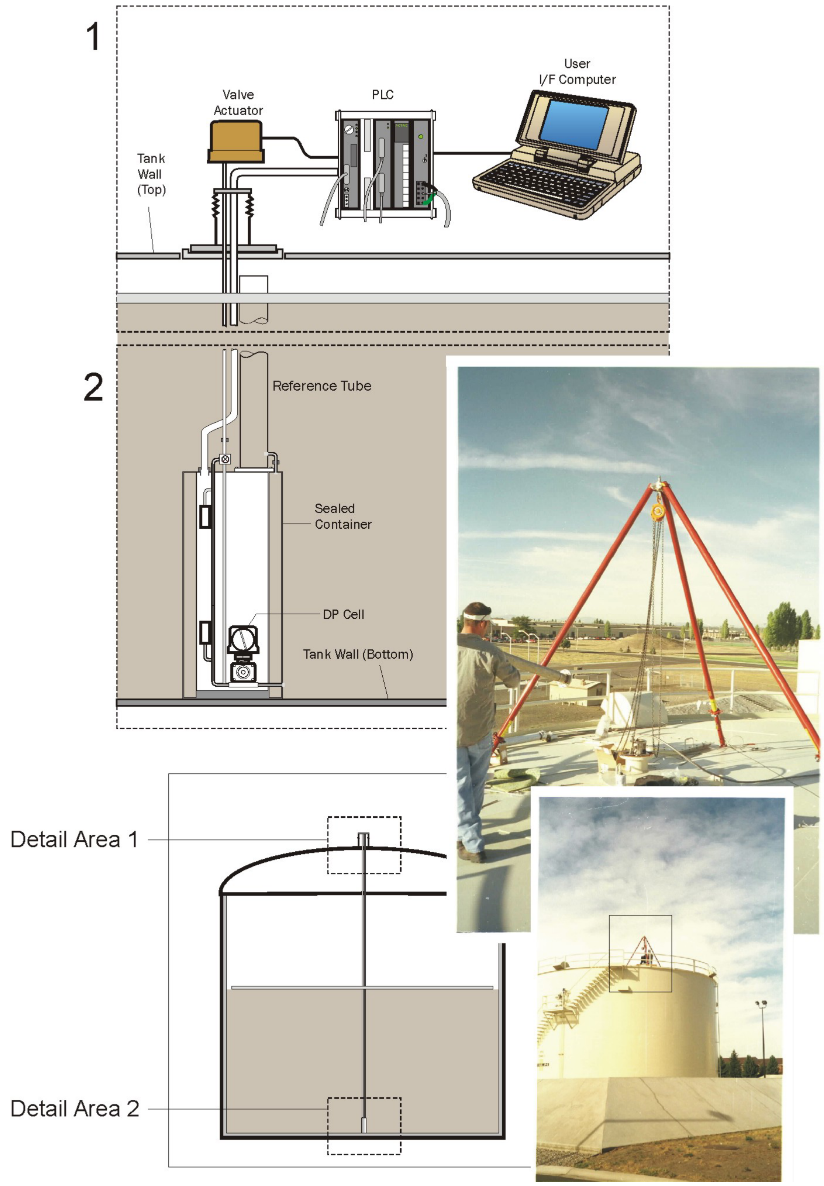

Figure 1. Low-Range Differential Pressure (LRDP) system for ASTs.

High performance is achieved with the LRDP system, because the novel design of the in-tank sensing unit results in (1) a very high precision for making level measurements with an off-the-shelf differential pressure (DP) sensor and (2) effective compensation of the thermally induced level changes produced by temperature changes of the fuel, the sensors, the tank, and the mounting system. Accurate compensation is obtained because the LRDP is specifically designed to compensate for each source of noise without the need for arrays of temperature sensors or delicate and expensive level sensors. As a consequence, all of the sensors are off-the-shelf, commercially available sensors that have a proven track record of performance. The reference tube, a special bellows-mounting stand at the top of the tank, bottom-mounted sensors, and externally mounted temperature sensor are the key elements that lead to high performance. Other mass-based systems do not work as well, because (1) the sensors are mounted at the top of the tank where the top of the tank moves vertically in response to large diurnal swings in the ambient air temperature, (2) the thermal expansion and contraction of the shell is not accurately compensated, (3) the pressure sensor is very delicate and expensive to achieve the level of precision required to conduct a test, and (4) the pressure sensor may require the use of nitrogen gas for operation.

A detailed description of the LRDP can be found in the final report [1]. A test is conducted after the valve at the bottom of the reference tube is closed. At the beginning of a test the level of the fuel in the tube is identical to that in the tank. With the exception of a level change due to a leak and the thermal expansion or contract of the tank wall, the level of the fuel in the reference tube mimics the level of the fuel in the tank. The DP sensor measures the difference in the levels of fuel between the reference tube and the tank (which can be expressed in terms of gallons per hour based on a height-to-volume conversion (HVC) from the tank's strapping table). The volume change is then compensated for the thermal expansion and contraction of the tank wall. The output of a test is a temperature-compensated volume rate (TCVR).

For high performance, a test should begin and end at night, and it should be long enough to average through a diurnal cycle. The TCVR is obtained by using two 30-min periods of data at the start and end of the test. It was intended that the test duration would be 24 h. However, to minimize the time required to conduct the third-party evaluation, the test was shortened to 20 h. This allowed a test to begin and end during the night and still leave sufficient time to prepare different leak conditions during the evaluation.

Once the data are qualified and a test result, TCVR, is computed, there are a variety of detection thresholds, T, that might be used to determine whether or not the AST has a leak. The detection threshold is set to maintain a specified probability of false alarm (P_{FA}) and a probability of detection (P_D) of 95% against the target leak rate of regulatory or operational interest. The largest P_{FA} that can be used is 5%. If possible, a P_{FA} of 1%, or less, should be used. The performance of the LRDP can be improved by averaging two or more tests together before applying the threshold, or by increasing the test duration. A test duration that extends through three night-time periods (two diurnal cycles) would give better performance than a test through only two night-time periods (one diurnal cycle).

Table 1 summarizes two general methods for conducting a test with the LRDP system that are designed to address the regulatory requirements summarized in Section 2.2. The name of the method contains the duration of the test in hours and the number of tests to be averaged. For ASTs, the LRDP-24 can be implemented with a test duration of 20-h, or longer. A waiting period is not required as it typically is for other in-tank leak detection systems.

Table 1. Summary of the Two Methods of the LRDP System for Bulk Tanks

Name of Test Method	Type of Test	Test Duration	Number of Tests Averaged Together
LRDP-24 Version 2	Monitoring, Precision*	20 h	1 test
LRDP-24-n Version 2	Precision*	20 h	$1 < n \leq 24$ tests

* Can be used to address the regulatory standards for a 0.20-gal precision test.

The LRDP-24-n is a test that requires the averaging of "n" LRDP-24 tests. As determined from the third-party evaluation reported herein, both methods can be used to test vertical-walled tanks with capacities greater than 50,000 gal and diameters less than 260 ft. Both the LRDP-24 and the LRDP-24-n can be used as a stand-alone monitoring and precision testing system or a portable precision testing system (as part of a testing service). The name of the method is designated as *Version 2* to differentiate the performance of the LRDP-24 for ASTs from the LRDP-24 for bulk USTs, which is designated as Version 1. For both methods in Table 1, one of five *detection thresholds* are presented that can be used to detect a specific target leak rate (TLR) with a P_D = 95%, or to operate with a specific $P_{FA} \leq$ 5%.

2.2 Process Description

Mobilization. The LRDP system can be transported to a measurement site in its main component sections. The reference tube is comprised of two or more sections of flanged pipe, which can be assembled on site during installation.

Test Set-up. The LRDP system can be installed for a test, when used as a portable system, in less than 4 hours. It takes between one and three days for a permanent installation of the in-tank sensing unit.

Precision and Accuracy. A detailed discussion of the precision and accuracy of the LRDP is given in Section 4.

Regulations. In 1988, the U. S. Environmental Protection Agency (EPA) issued regulations that required periodic leak testing of underground storage tanks and their associated piping containing hazardous substances such a petroleum fuels that *deferred* the requirements for testing ASTs and field-erected (i.e., bulk) USTs for leaks [11], mainly because there were no viable technologies available in 1988 for accurately testing ASTs. As a consequence, none of the ASTs were required to meet the rigorous leak-detection performance standards for monthly monitoring or annual tightness testing established for the smaller, shop-constructed USTs typically found at retail petroleum service stations [11]. While an aboveground tank is defined as any tank with less than 10% of the volume of the fuel contained underground, the bottom or buried surface area of an AST with a diameter of 31.3 ft, a very small AST, has the same buried surface area as a 10,000-gal UST, one of the larger shop-constructed USTs found at many retail service stations.

While there are no federal leak-detection regulatory requirements for ASTs, it is safe to assume that the states will implement regulations or regulatory guidelines similar to those used for testing bulk USTs [12]. Also, while not required, the latest version of the Spills Prevention, Control and Countermeasures (SPCC) regulation strongly encouraged leak detection as part of each storage facilities inspection and maintenance plan [13]. Owners and operators of *field-erected, bulk USTs* and *hydrant systems* are now highly regulated; strong regulations for owners and operators of ASTs will soon follow. Even more importantly, there is an operational driver for implementing leak detection in ASTs. In most states, the regulatory environment requires ASTs to have double-bottoms with leak detection in the interstitial space between the false existing and second bottom. As an alternative, these states will accept single-bottom tanks if reliable leak detection is permanently installed on the tank for routine monitoring and periodic precision testing. This option is very real and very attractive, because there is a cost savings of as high as 30:1 over that of double bottoms. Moreover, a major oil company has recently issued internal requirements to test their single-bottom ASTs every two years as compared to no testing.

Training. A field technician with experience in operating computer-controlled equipment can learn to operate the system in less than a day. The physical set-up of the equipment and the methods for mounting the LRDP in the tank is straightforward. The system checkout and use of the software is also straightforward. The system is automatic and a test is initiated by clicking on the start button on the Graphical User Interface (GUI).

Health and Safety. The LRDP system is safe to use and poses no health risk to the user or the AST. The system requires 110 VAC power, but can and was operated off of a generator when used as part of a testing service.

2.3 Previous Testing of the Technology

Over the past six years, the NFESC, in conjunction with its industrial partners, has developed, evaluated and implemented the LRDP leak-detection system for bulk USTs [4-10]. The LRDP has been evaluated for performance by a third party following an EPA standard test procedure for bulk USTs [14, 15] and bulk ASTs [16]. Three separate third-party evaluations have been performed in tanks of different sizes, locations, and climatic conditions. The evaluations were performed (1) in an 88-ft-diameter bulk UST containing 650,000 gal of fuel at the NAS North Island [4, 17-25], (2) in a 122.5-ft-diameter bulk UST containing 2,100,000 gal of fuel at the Point Loma Fuel Terminal[7-8, 26-33], and (3) in the world's largest tanks having a diameter of 100 ft and containing 12,500,000 gal of fuel [5, 9, 34]. The system has also been demonstrated on a 50,000-gal, shop-fabricated UST at the Hunter Army Air Field, Fort Stewart [7, 8]. The results of all three evaluations were similar and are consistent with the results of the LRDP obtained in this AST third-party evaluation [35-40]. The results of these evaluations have demonstrated that the LRDP, both as an on-line, permanently installed system and a portable system used as part of a testing service, has the performance to meet the very strict regulatory compliance standards in bulk USTs that were established for the highly regulated small USTs found at retail service stations and bulk USTs in California [11-12].

2.4 Advantages and Limitations of the Technology

The LRDP system has the following advantages for testing ASTs:

- The LRDP can be directly inserted into a standard 8-in.-diameter opening in the tank, and can be installed and used without removing fuel from the tank.
- The LRDP can be used to test a bulk ASTs in as little as 20 h, which is significantly shorter in test duration than other methods (48 to 72 h or longer).
- The output of a leak detection test is easy to interpret, because it is a direct measurement of the leak rate in gallons per hour, the quantity of regulatory and engineering interest.
- The LRDP system is the only mass-based system that can meet both the monthly monitoring and the semi-annual or annual precision test regulatory guidelines required in California for testing bulk USTs.

The main limitation of the method is that all of the valves in the fuel facility that isolate the tank from its associated piping must seal completely. If closing the valves more tightly does not work, valve blinds may need to be installed to complete the test. The magnitude of this problem is not known for bulk ASTs, but it is the same problem encountered and successfully addressed for routine monitoring of USTs at service stations and bulk USTs at DoD facilities.

3.0 Demonstration Design

3.1 Performance Objectives

The objective of this ESTCP project was to demonstrate and validate (DEM/VAL) a reliable, cost-effective leak-detection system for monthly monitoring and periodic precision testing of the *bulk* aboveground storage tanks (ASTs) that are owned and operated by the DoD. This project was an expansion of the previous ESTCP project conducted for bulk USTs [7-9]. The DEM/VALs were designed to demonstrate the system on fixed-roof tanks with and without a floating pan and to have the performance documented in a third-party evaluation. The output of the project is a pre-production prototype of the LRDP leak detection system (1) that is ready for use by industry and (2) that has been evaluated for performance by an independent third party following a *standard test procedure* developed by the EPA and ASTM [15-16].

The performance objectives of the DEM/VALs were established by the regulatory guidelines developed in California for detection of leaks in *bulk* USTs [12]. The bulk UST regulatory guidelines were used, because quantitative standards for ASTs have yet to be developed. Furthermore, these regulatory standards are practical and very stringent.

The results of this evaluation are reported in terms of a probability of detection (P_D) of a target leak rate (TLR) and a probability of false alarm (P_{FA}). At a minimum, the P_D must be equal to or better than 95% and the P_{FA} must be less than or equal to 5%. The TLRs for bulk USTs are typically 0.3 to 1.0 for monthly monitoring when a precision test at 0.2 gal/h is performed annually and 1.0 to 2.0 gal/h for monthly monitoring when the precision test is performed semi-annually [12].

3.2 Selection of a Test Site/Facility

Since the LRDP leak-detection system is not affected by soil conditions and site geology, four criteria were used in selecting sites for the DEM/VALs. The primary criteria for a demonstration site are AST size, type of tank, tank integrity, and tank availability and base facility support. First, it was desired to perform the DEM/VAL in a tank with a large enough diameter to address all of the tanks used by DoD. The standard test procedure for bulk ASTs described in [16] allows the results of the evaluation for mass-based systems in a bulk UST to be used for any tank smaller than the tank used in the evaluation and any tank whose product surface area (PSA) is less 250% of the PSA of the evaluation tank. Second, it was desired to demonstrate that the system can be used in any type of tank owned by DoD. There are two basic types of ASTs: (1) fixed-roof tanks and (2) fixed-roof tanks with floating pans. Thus, two DEM/VAL sites were used, one with each type of tank. Third, the tanks used in the DEM/VALs had to be free of leaks, and it was desired that no inflow or outflow due to leaking valves occur during the evaluation. Two DoD facilities offered the use of their ASTs for the evaluation: (1) FISC Pearl Harbor and (2) Fairchild Air Force Base.

The FISC Pearl Harbor site was selected for the third-party evaluation, because of the (1) the large size of the tanks storing fuel, (2) the valves isolating the tanks from the transfer piping were new double-block and bleed valves whose the integrity could be verified, (3) it was the most common type of AST owned and operated by DoD, and (4) the need and interest of the fuel farm for a cost-effective system for testing the tanks at the facility. The Fairchild AFB site was selected for the DEM/VAL, because the site had fixed-roof tanks contained floating pans, and there was on-site support and interest in fielding a DEM/VAL.

Figure 2. Photograph of the FISC Pearl Harbor tank used to evaluate the LRDP system. The 8-in.-opening with part of the LRDP mount in place and the bottom catch basket to keep the LRDP stable are shown in the photograph on the left and right, respectively.

3.3 Test Facility History/Characteristics

A brief description of the FISC Pearl Harbor and Fairchild AFB DEM/VAL sites is provided below. For more details, see the ESTCP Demonstration Plan [3].

3.3.1 DEM/VAL 1: Fairchild Air Force Base

The first DEM/VAL was conducted on Tank #2 of the KC-135 Hydrant Fueling system that is adjacent to Pump House B. The tank is a 10,000-barrel (400,000 gal), 54-ft-diameter, fixed-roof AST (with a floating pan) at Fairchild AFB, Spokane, Washington. The main objective was to demonstrate that a fixed-roof AST with a floating pan could be reliably tested without resting the floating pan on its legs at the bottom of the tank.

3.3.2 DEM/VAL 2: FISC Pearl Harbor (Third-Party Evaluation)

The second DEM/VAL was conducted on Tank #56, a 150,000-barrel (6,470,000-gal), 164.5-ft-diameter fixed-roof AST at Pearl Harbor, Hawaii and is one of the largest field-erected bulk

ASTs owned by DoD. The tank is 164.5 ft in diameter and was filled to a depth of 40.7 ft. It contained 6,470,000 gals of JP-5 fuel. The product surface area (PSA) of the tank is 21,253 ft^2. Level changes in this tank are converted to volume changes using a height-to-volume conversion (HVC) factor of 13,248.6 gal/in. The sensitivity of the LRDP to product transfers in and out of the tank was tested by removing from the tank and then adding back over 2,500,000-gal of fuel.

3.4 Physical Set-up and Operation

The first DEM/VAL was conducted on a 54-ft-diameter, fixed-roof AST at Fairchild Air Force Base This tank was used because it contained a floating pan. The second DEM/VAL was conducted on a 164.5-ft diameter, fixed roof AST at FISC Pearl Harbor. This tank was used because it is one of the largest ASTs owned by the DOD. Both tanks have vertical walls and a sloping bottom. The third-party evaluation was performed on the larger tank. The tests performed on the smaller tank were used to verify that the floating pan did not interfere with a leak-detection test.

3.4.1 DEM/VAL 1: Fairchild Air Force Base

The primary objective of the DEM/VAL conducted at the Fairchild Air Force Base was to demonstrate that the system could be used to test fixed-roof tanks with floating pans for leaks. The LRDP was installed in the tank and checked out during the last week in September 2001. Representatives from Vista Engineering Technologies and Vista Research were present for the installation (and the removal). Approximately five months of data were collected to check out the LRDP and verify its operation in a tank with a floating pan. The tank contained 400,000 gal (95% of capacity) of JP-5 for these tests.

Figure 1 shows the LRDP being installed in the tank through the standard 8-in.opening in the top of the tank. The reference tube was installed in the 8-in.-diameter measurement fill tube. The fill tube extends from the top of the tank to the bottom of the tank and was located approximately one-third of the distance from the wall to the center of the tank. The bottom elevation of the fill tube is at the same elevation as the ground at the side of the tank. The bottom of the tank has about a 5 degree slope, which means the bottom of the tanks is about 28 in. lower in elevation than the bottom of the fill tube. In this configuration, a differential pressure sensor will not completely compensate for the thermal expansion or contraction of the fuel because of the fuel below the pressure sensor. This problem could have been addressed by locating a temperature sensor at the bottom of the reference tube or by installing the reference tube at the center of the tank and appropriately shaping the bottom 3-ft of the tube to match the changing cross-sectional area of the tank. This was done for the tank at FISC Pearl Harbor.

Three types of tests were conducted. The first and most important test was to demonstrate that accurate level measurements could be made in a fixed-roof tank with a floating pan. A calibration test was performed. Measured volumes of product were removed from the tank and compared to the volumes measured with the LRDP using the HVC of the tank. The second test was to investigate the thermally induced volume changes of the wall. This was done using temperature sensors mounted to the external wall of the tank at the North, Southeast and Southwest sides of the tank. The third type of test was to conduct a leak detection test.

The floating pan could degrade a test in two ways. First, the pan could partially stick on the side of the wall during a test. When the floating pan moves freely, the HVC is determined by the cross-section geometry of the product surface. If the pan sticks, the measured HVC would be many of orders of magnitude larger than the actual HVC for the entire tank. Thus, when the pan is stuck, even small volume changes would produce excessively large height changes because of the small product surface area available for vertical movement as compared to the product surface area of the tank itself. As a consequence, it is relatively easy to identify any sticking of the pan. A leak detection test can be performed, even if the pan temporarily sticks during the test, if the pan is freely moving at the beginning and end of the test, or if the pan is stuck during the entire test and the actual HVC has been measured for this condition. In any other condition it is difficult to assess the volume change during the transition periods.

3.4.2 DEM/VAL 2: FISC Pearl Harbor (Third-Party Evaluation)

The LRDP was installed in the tank and checked out during the second week of May 2002. Representatives from KWA, Vista Research, and Vista Engineering were present. The LRDP was installed in an 8-in. opening at the center of the tank (Figure 2). A special catch basket was installed in the tank when the tank was cleaned to insure that the LRDP did not move when the transfer pumps, which were aimed directly at the LRDP, were turned on. The bottom 3 ft of the reference tube was shaped to mimic the changing cross sectional area at the bottom of the tank due to the sloping bottom. The same tripod installation system was used on the FISC Pearl Harbor tank that was used on the Fairchild tank. The LRDP was installed and checked out in a day. The data from two 10-day data-collection periods were obtained in May and early June before the start of the evaluation to verify the system was function properly.

The performance of the LRDP was evaluated by Ken Wilcox Associates during tests conducted between June 19 and August 29, 2002. Twenty-four (24) tests were conducted, during which KWA randomly introduced leaks ranging from 0.0 to 2.0 gallons per hour. Neither the presence of the leaks nor their size was known to the vendor until after the completion of all of the evaluation tests and all of the test results had been reported. The evaluation results are tabulated in Table2.

KWA also examined whether the LRDP was sensitive to effects related to the filling of the tank; the results of the evaluation showed no adverse impact on the performance of the LRDP even if a test was started immediately after the tank had been filled. The mean and standard deviation of the evaluation results were –0.004 gal/h and 0.272 gal/h, respectively. A statistical hypothesis at a level of significance of 0.05 showed that there was no statistically significant bias in the test results; as a consequence, the performance of the method is computed from only the standard deviation of the test results.

The bulk AST evaluation protocol [16] is similar to the bulk UST protocol [14]. The two major differences between the evaluation protocols. First, 24 tests were required by the AST protocol vice 12 tests for the UST protocol. Second, the requirement for at least six transfers was eliminated, because such transfers do not affect mass-measurement systems. However, to demonstrate this, a special removal and addition of fuel to simulate a transfer was conducted. The addition tests were added to get a more representative set of ambient conditions than would be provided with only 12 tests and is consistent with the UST protocols for shop-constructed USTs.

The evaluation procedure requires that the evaluation be performed when the tank is approximately 90% of capacity. Leaks were produced by pumping fuel out of the tank with a peristaltic pump. The protocol requires at least six leaks. Eleven leaks were generated by KWA. Leaks of approximately 0.5, 1.0, and 2.0 gal/h were randomly induced during the evaluation. This blind testing insures the integrity of the evaluation.

Testing during the evaluation was accomplished by KWA personnel following the LRDP testing procedures specified by NFESC and Vista Engineering. Leak simulations and fuel deliveries were defined and monitored by KWA. Leaks were induced by KWA with a peristaltic pump through a valve located on the side of the tank. The LRDP system routinely monitored the results of each test. The output of each test was automatically output from the system. A test duration of 20 h was used. A shorter test duration than 24 h allowed a new test condition to be generated each day.

For bulk ASTs, the LRDP requires that a test be started and completed during darkness. Starting and ending the test at night minimizes the thermally induced changes to the wall of the tank and allows a single temperature sensor to be used for compensation. Accordingly, during the evaluation, KWA changed the induced leak rate each day at 0400. Induced leaks were generated for the first 11 tests. Given that it could take KWA anywhere between several minutes and up to 30 min to change the leak, Vista Engineering started and ended the test at 0530 and 0130, respectively. This insured that the induced leak had been established for each test. No interruptions to the testing occurred during the evaluation.

For each test, the volume rate measured by the LRDP system was compared to the leak rate induced by KWA. Neither the nominal nor actual leak rate was made known to NFESC or Vista Engineering until many months after the evaluation had been completed and the final evaluation report was prepared. Leak rates were calculated from the total mass of fuel removed from the tank during the test and the density of the fuel that was measured with an analytical balance in a laboratory. The mass of the fuel removed from the tank was measured by pumping the fuel into a barrel hanging from a load cell. The uncertainty in the induced leak rates was less than 0.01 gal/h. During each test, KWA also verified the magnitude of the induced leak rate by measuring the pump rate with a graduated cylinder and a stop watch.

The measured volume rates measured by the LRDP are presented in Table 2. As part of the tests, data quality indices automatically checked to verify the quality of the data and to determine whether or not the tank was inadvertently used during the test (e.g., product transfers, or fuel or water sampling). The difference between the measured volume rate and the induced volume rate are also presented in Table 2. The volume rate errors are used to develop the performance of the LRDP system.

3.5 Sampling/Monitoring Procedures

The third-party evaluation of the LRDP was conducted by Ken Wilcox Associates, Inc. (KWA) in accordance with a protocol develop especially for ASTs by KWA [16] that is consistent with the protocol developed previously and used for bulk USTs [14]. This evaluation test procedure follows EPA and ASTM standards for conducting and reporting the results of a third-party evaluation [15, 16]. These standards describe the means for demonstrating the performance of bulk tank leak detection systems.

Table 2. Summary of the Third Party Evaluation Test Results Obtained in a 164.5-ft-Diameter AST at FISC Pearl Harbor

Start Date At 0530 HST	**End Date** At 0130 HST	**Compensated Test Result (CTR)** (gal/h)	**Induced Leak Rate (ILR)** (gal/h)	**Error = (CTR- ILR)** (gal/h)
6/19/2002	6/20/2002	-0.081	0	-0.081
6/20/2002	6/21/2002	-1.945	-1.902	-0.043
6/21/2002	6/22/2002	-0.214	-0.517	0.303
6/22/2002	6/23/2002	-1.626	-1.066	-0.560
6/23/2002	6/24/2002		-0.517	
6/24/2002	6/25/2002	-1.801	-1.869	0.068
6/25/2002	6/26/2002	-0.590	-0.851	0.261
6/26/2002	6/27/2002	-1.819	-1.75	-0.069
6/27/2002	6/28/2002	-0.946	-1.364	0.418
6/28/2002	6/29/2002	-0.738	-0.786	0.048
6/29/2002	6/30/2002	-1.403	-0.884	-0.519
6/30/2002	7/1/2002	-0.691	-0.391	-0.300
7/1/2002	7/2/2002	0.113	-0.089	0.202
7/2/2002	7/3/2002	0.295	0	0.295
7/3/2002	7/4/2002	-0.056	0	-0.056
7/4/2002	7/5/2002	-0.084	0	-0.084
7/5/2002	7/6/2002	-0.335	0	-0.335
7/6/2002	7/7/2002	-0.216	0	-0.216
7/7/2002	7/8/2002	0.114	0	0.114
8/23/2002	8/24/2002	0.271	0	0.271
8/24/2002	8/25/2002	0.238	0	0.238
8/25/2002	8/26/2002	-0.112	0	-0.112
8/26/2002	8/27/2002	0.250	0	0.250
8/27/2002	8/28/2002	0.165	0	0.165
8/28/2002	8/29/2002	-0.362	0	-0.362

3.6 Analytical Procedures

The average of a 30-min segment of data obtained by the DP sensor and the AST wall temperature sensor data were used to compute the change in the LRDP volume and the Wall Volume over a 20-h period. The output of a leak detection test, the temperature compensated volume rate (TCVR), was computed over this 20-h period as follows:

$$TCVR = [HVC\ (\langle LRDP_{End}\rangle - \langle LRDP_{Start}\rangle) - (\langle \text{Wall Volume}_{End}\rangle - \langle \text{Wall Volume}_{Start}\rangle)]/20,$$

where, the average is denoted by < >. More details on the computation can be found in [1].

4.0 Performance Assessment

4.1 Performance Data

The performance of the LRDP system was assessed for its suitability for both monthly monitoring and for annual or semi-annual precision (tightness) testing of ASTs using the results of many 20-h leak detection tests conducted at both Fairchild Air Force Base and FISC Pearl Harbor. The performance data from the third-party evaluation used to determine whether or not the performance criteria are met are presented in Section 3. Section 4.2 describes the performance criteria and Section 4.3 describes the data assessment.

4.2 Performance Criteria

The performance criteria of the DEM/VALs were established by the regulatory guidelines developed in California for detection of leaks in *bulk* USTs [12], because quantitative standards for ASTs have yet to be developed, but will be no more stringent than those implemented for bulk USTs. The performance of a leak detection method is evaluated and reported in terms of a probability of detection (P_D) of a target leak rate (TLR) and a probability of false alarm (P_{FA}). At a minimum, the P_D must be equal to or better than 95% and the P_{FA} must be less than or equal to 5%. The TLRs for bulk USTs are typically 0.3 to 1.0 for monthly monitoring when a precision test at 0.2 gal/h is performed annually and 1.0 to 2.0 gal/h for monthly monitoring when the precision test is performed semi-annually. Whether or not the performance criteria are met is determined by a third-party evaluation. The LRDP system was evaluated for a 20-h test duration.

4.3 Data Assessment

Section 4.3.1 describes the results of the third-party evaluation performed by Ken Wilcox Associates, Inc., (KWA) during the DEM/VAL conducted at FISC Pearl Harbor, and Section 4.3.2 describes the results of the tests conducted during the DEM/VAL conducted at the Fairchild Air Force Base to show that leak detection tests can be performed in fixed-roof ASTs with floating pans.

4.3.1 Third-Party Evaluation Results (FISC Pearl Harbor DEM/VAL)

Ken Wilcox Associates describes the results of two evaluations of the LRDP for detecting leaks in ASTs in two separate final reports, one for the LRDP-24 Version 2 [35-37] and one for the LRDP-24-n Version 2 [38-40]. Five performance estimates are presented for each method, one in the *Final Report* for that method, and four more in a separate volume called *Volume 1: Results Forms*. The test logs are also included, but in another volume called *Volume 2 : Log Sheets*.

4.3.1.1 FISC Pearl Harbor Test Results

An example of the ambient level data measured with the LRDP over a 72-h period is shown in Figure 3. The thermally induced volume changes produced by the thermal expansion and contraction of the tank wall is also shown in Figure 3; the temperature data used to make this estimate were obtained from one RTD mounted on the North wall of the tank. It is clear that the fluctuations in the level data are mainly a function of the thermal expansion and contraction of the wall. However, it is also clear that not all of the level changes measured during a complete diurnal cycle are quantitatively explained by this wall estimate, especially during periods when the sun shines directly on the wall of the tank. As a consequence, as described in Section 2.1, a test is begun and ended at night, when the sun cannot produce uneven heating of one side of the tank or another, and only the change in level from one night-time period to the next is used in the analysis. A test should not be initiated until the entire wall of the tank is uniformly changing temperature. Thus, a test should not be initiated for several hours after sunset. For these measurements, all tests were begun and ended after midnight.

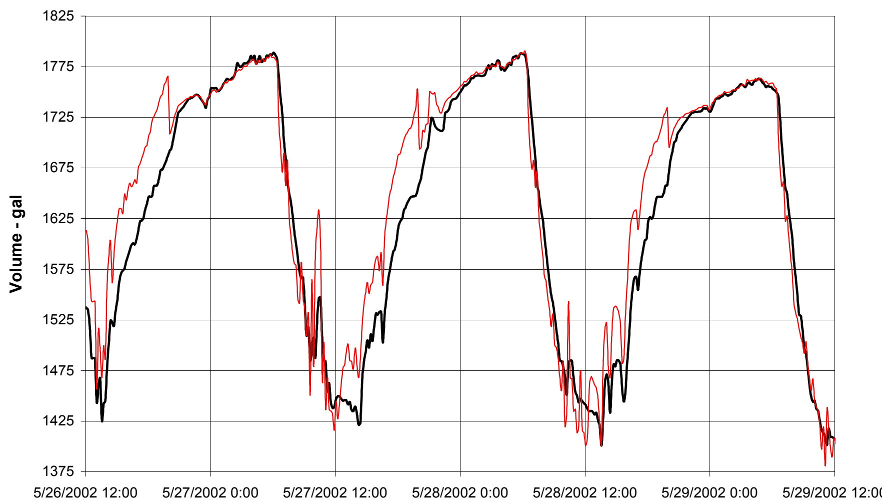

Figure 3. Level and shell-temperature data in gallons that were obtained with the LRDP-24 system during the pre-evaluation LRDP tests.

There are a variety of reasons that might explain the differences between the measured level (volume) changes with the DP sensor and the level (apparent volume) changes produced by the thermally induced wall changes. First, a single temperature sensor is not adequate to fully characterize the wall temperature changes over the vertical extent of the tank. Second, a model was assumed to compute the volume changes produced by the wall as it thermally expands and contracts due to temperature may not be accurate enough. Third, other sources of error, like bottom lift, where the thermal expansion and contraction of the fuel beneath the DP cell is not compensated. Temperature data obtained at the bottom of the tank indicated that the shaped tube in the bottom three feet of the tank compensated for the bottom lift.

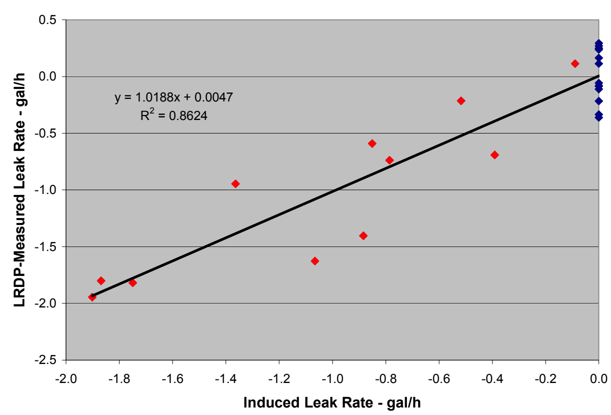

Figure 4. Least-squares lines fitted to the test results of the LRDP-24. The tests conducted with induced leaks are shown in red.

In Figure 3, the level data were converted to volume using the HVC = 13,248.6 gal/in. These data are illustrative of the type of data obtained during the evaluation. It is clear that a test begun at 0530 and ended at 0200 would produce accurate results, but a test begun and ended at noon would not.

The results of the leak detection tests for the LRDP-24 that were presented in Table 2 are summarized graphically in Figure 4. Each test result is plotted against the leak induced for that test. In Figure 4, the test results measured by the LRDP systems appear on the y-axis, while the KWA-induced leak rates appear on the x-axis. A least-squares line has been fitted to the results of the tests with each LRDP system. The slope of the line is nearly 1.0 (1.019 for all 24 of the evaluation tests and 1.012 for the 11 induced leak evaluation tests); this indicates that the volume changes due to the induced leaks are additive with any other volume changes in the tank.

A summary of the statistics of the LRDP-24 determined in the evaluation is presented in Table 3. The performance in terms of P_D and P_{FA} are determined from the standard deviation, S, assuming that the histogram of the noise and signal-plus noise are normally distributed. Once the standard deviation is known, the performance can be computed for any P_D and any P_{FA}.

Table 3. Mean and Standard Deviation of the Difference between the Measured Leak Rates (Test Results) and Induced Leak Rates for the LRDP-24

Type of LRDP System	**Number of Tests**	**Mean Volume Rate** (gal/h)	**Standard Deviation** (gal/h)
LRDP-24	24	-0.004	0.272

A statistical hypothesis test was performed, as required by the evaluation protocol, to determine if the mean was statistically different from zero. A two-sided student-t test was conducted at a level of significance of 0.05. The conclusion of the hypothesis test was that that the mean could not be distinguished statistically from zero, and as a consequence, the method has no bias. This is consistent with the results obtained for the LRDP when used for bulk USTs [4, 7-8, 17-40].

The performance of a leak detection system can be affected by the size and geometry of the tank. This relationship is not quantitatively understood for volumetric methods, but is predictable for mass-based systems like the LRDP system. For most mass-based technologies, performance is proportional to the product surface area of the fuel in the tank. According to the evaluation protocol [14, 16], the maximum tank size to which a mass-based method may be applied is determined by the product surface area of the tank, A_{eval}, and is limited to two and one-half times (250%) the surface area of the tank used in the evaluation. Since the surface area of the 164.5-ft diameter, 6,470,000-gal tank used in this evaluation is 21,253 ft^2, the LRDP-24 can be used to test tanks with diameters up to 260 ft. The maximum tank capacity (in terms of volume of fuel in the tank) that can be tested with the LRDP systems is not constrained by the evaluation and will depend on the height of the tank.

4.3.1.2 Performance Estimates for a Single Test (LRDP-24)

Estimates of the performance of the LRDP-24, in terms of P_D and P_{FA}, were generated for the *evaluation tank* from the *standard deviation, S,* given in Table 4. The minimum detectable leak rate (MDLR) is tabulated in Table 5 for the 164.5-ft-diameter evaluation tank and is the leak rate that can be detected with a P_D = 95% and a P_{FA} = 5%. The MDLR is determined from the 24 tests

Table 4. Estimate of the Minimum Detectable Leak Rate (MDLR) for the LRDP-24 in a 164.5-ft Diameter AST

Type of LRDP System	**Threshold (gal/h)**	**Leak Rate (gal/h)**	**Probability of False Alarm (%)**	**Probability of Detection (%)**
LRDP-24	0.466	0.932	5.0%	95.0%

performed in the evaluation by multiplying the standard deviation, S, by 3.428. The 3.428 value is twice the value obtained from a Student's t Distribution table for 23 degrees of freedom and a one-tailed test for a level of significance of 0.05 (see reference [14] for more details).

The formula for computing performance of the LRDP-24 (when n = 1) and the LRDP-24-n are presented and discussed in the final report [1]. Version 2 of the method, which is summarized in the final reports prepared by KWA, allows the user to select a specific TLR for the tank to be tested in such a way that the P_D = 95% and the P_{FA} is less than or equal to 5.0%. The P_{FA} will change for each size tank tested if the same TLR is desired.

Four values of the TLR_{eval} were selected to estimate the performance of the LRDP during the third party evaluation: (1) 0.93 gal/h (Version 2.2, MDLR); (2) 1.15 gal/h (Version 2.0, P_{FA} = 1%); (3) 1.86 gal/h (Version (2.1, 2MDLR); (4) 3.5 gal/h (Version 2.0). These TLRs were selected to achieve a certain include certain a P_{FA} for a P_D = 95% and allowed the TLR to scale with tank size without changing the P_D or P_{FA}. For these TLRs, this results in the following P_{FA}s: (1) 5%, (2) 1%, (3) 0.0016%, and (4) very much less than 0.001%. Only four TLRs were selected, because the NWGLDE only allows the performance for four TLRs to be listed, and these four cover the most typical testing requirements in terms of TLR and P_{FA}. (However, other values of TLR are possible if the tank operator needs to operate the system in a specific manner.)

4.3.1.3 Performance Estimates for More than One Test (LRDP-24-n)

The performance of the LRDP-24 (or any leak detection system) can be improved significantly by combining the results of two or more tests. Averaging two or more test results before applying the threshold will improve *both* the probability of detection and the probability of false alarm over that obtained for a single test. Performance improves as the number of tests averaged together increases. The performance will depend on the test duration and the number of tests, n, averaged together. For example, the performance of the LRDP-24-4 is a factor of 2.0 (square root of 4) times better than a single 20-h test with the LRDP-24; the LRDP-24-4 uses a test duration of 20 h and averages four 20-h tests together.

The performance of the LRDP-24-n systems, where n is the number of independent tests averaged together, is obtained using the *standard deviation of the mean, S_m,* test result, S_m, of the LRDP-24, rather than the *standard deviation, S,* obtained from the evaluation, where S_m, is given by

$$S_m = S /(n)^{0.5} .$$

Averaging is important because it allows all of the bulk ASTs owned or operated by DoD to meet the precision test requirements of 0.2 gal/h.

4.3.1.4 Summary of Performance Results for Different Size Bulk ASTs

Table 5 presents the largest tank that can be tested (for the number of tests averaged together) to meet the P_D and P_{FA} specified in the table. The performance results are summarized in Table 5 for the MDLR as a function of tank diameter and the number of tests, n, averaged together. The table indicates the largest tank that can be tested and still maintain the prescribed performance in terms of the P_D and P_{FA}. The performance of the LRDP is proportional to the cross-sectional area of the product surface (i.e., the diameter of the tank) and is inversely proportional to the square root of the number of independent tests averaged together. Thus, the smaller the area (or tank diameter) and the large the number of tests averaged together, the better the performance.

The MDLR is presented at the top of each table. Most regulatory agencies require at least this level of performance. In addition, the MDLR is the most straightforward way to compare the performance of different methods. The MDLR attainable in a single test was computed, as well as that attainable by averaging several tests. The LRDP's MDLR for the tank used in the evaluation (i.e., the one with a diameter 164.5 ft) is 0.932 gal/h, and the threshold (the volume rate at which a leak would be declared) is 0.466 gal/h. The results of this evaluation are applicable to ASTs with diameters up to 260.1 ft.

Table 5. Largest Tank Diameter that Can Be Tested with a P_D = 95% and a P_{FA} = 5% as a function of Leak Rate and Number of Tests, n, Averaged Together

				n = 1	n = 2	n = 4	n = 6	n = 12
Leak Rate (gal/h)	**Threshold** (gal/h)	**P_D** (%)	**P_{FA}** (%)	**Tank Diameter** (ft)	**Tank Diameter** (ft)	**Tank Diameter** (ft)	**Tank Diameter** (ft)	**Tank Diameter** (ft)
0.93	0.466	95%	5%	164.5	195.6	232.6	257.5	$\leq$ 260.1
0.20	0.100	95%	5%	76.2	90.6	107.8	119.3	141.8
0.30	0.150	95%	5%	93.3	111.0	132.0	146.1	173.7
0.50	0.250	95%	5%	120.5	143.3	170.4	188.6	224.3
1.00	0.500	95%	5%	170.4	202.6	241.0	$\leq$ 260.1	$\leq$ 260.1
2.00	1.000	95%	5%	241.0	$\leq$ 260.1	$\leq$ 260.1	$\leq$ 260.1	$\leq$ 260.1

4.3.2 Results of the DEM/VAL of the LRDP in a Fixed Roof-Tank with a Floating Pan

Results from the Fairchild AFB DEM/VAL are presented below. The main purpose of this DEM/VAL was to demonstrate that a fixed-roof AST with a float pan could be tested with the LRDP. A calibration test was performed in which a known volume of fuel was withdrawn from the tank. Nominal volumes of 2, 5, 10, and 15 gal were withdrawn. Figure 5 shows the LRDP-measured level change in inches during the calibration test. The volume of fuel withdrawn is annotated on the figure. For a 54-ft-diameter tank, the geometrical or theoretical estimate of the height-to-volume calibration (HVC) for the tank would be 1,427.7 gal/in. Thus, theoretically, a 10-gal withdrawal should result in a 0.0070-in. level change, which is about the level shown in Figure 5 for this volume of withdrawal. If the pan stuck and only had two 8-in.-diameter openings and a 6-in. annual between the floating pan and the inside wall of the tank, the geometrical HVC with the pan stuck would be 26.75 gal/in. This is 53.4 times smaller than the expected HVC of the tank. Thus, a 10-gal withdrawal would result in a 0.374-level change if the pan was stuck and did not freely float during the withdrawal. Because a tank operator would assume that the pan does not stick, the geometrical HVC of 1,427.7-gal/in. f be applied, and the actual 10-gal withdrawal would appear to produce a 533.7 gal change. Thus, it should be fairly obvious to the tank operator if the pan sticks during a test.

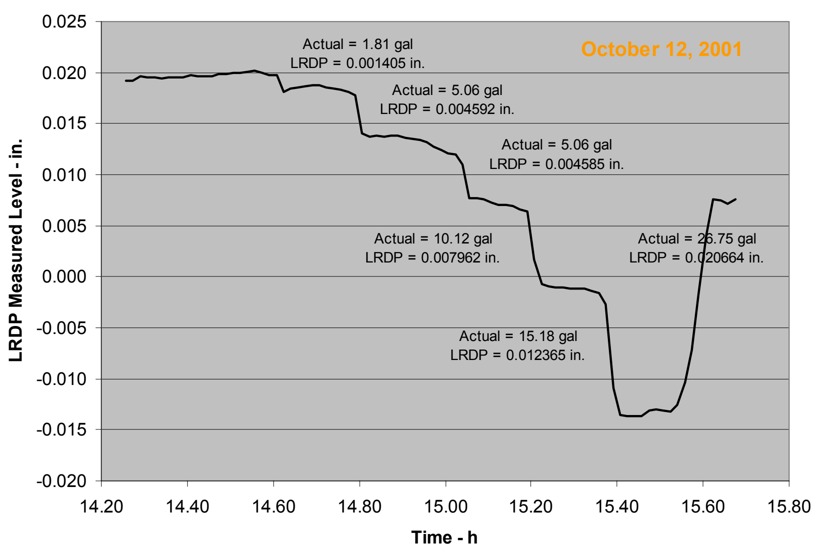

Figure 5. Height-to-volume calibration test results for the 54-ft-diameter fixed-roof AST with a floating pan at Fairchild Air Force Base.

There are two interesting observations about the withdrawals in Figure 5. First, small level changes are easily measured. Even the 1.8-gal withdrawal, which should produce a 0.0012-in. level change, is easily discernible. Second, all of the withdrawals seem to produce level changes that are slightly higher than expected. The 10-gal withdrawal produces a 0.0079-in. change vice the expected 0.007-in. change.

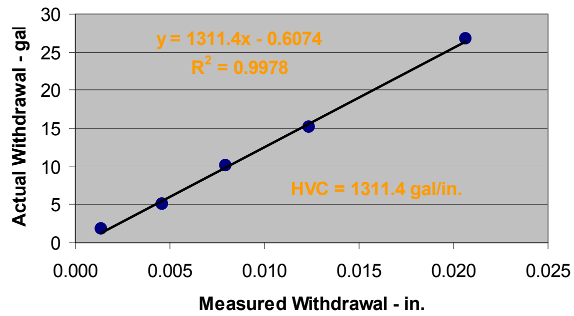

Figure 6. Computation of the HVC from the calibration measurements shown in Figure 7. The measured HVC = 1311.4 gal/in.

Figure 6 shows a plot of the actual withdrawal versus the LRDP-measured level change. The slope of the line, 1,311.4 gal/in, gives the HVC for the tank, which is 8.1% lower than the geometrical calibration. While such an error is not unreasonable for a field check of the HVC, especially if the diameter of the tank is less than 54.0 ft, it is likely that this difference is partially due to some drag due to the sealing skirt at the pan perimeter and any guides used to prevent pan rotation.

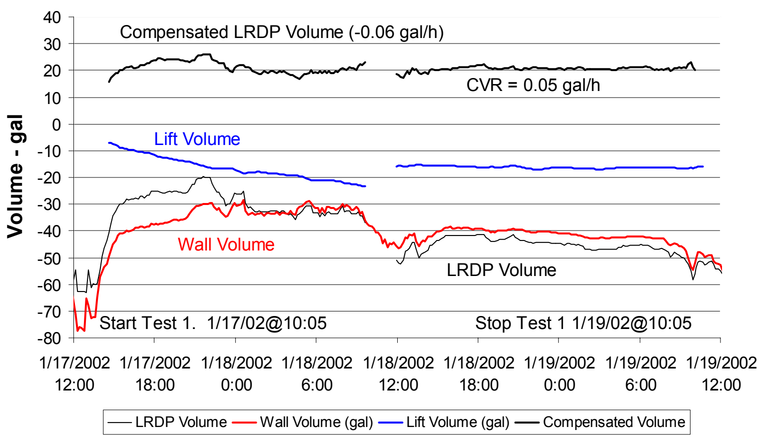

Figure 7. Results of the first test conducted by KWA without introducing an induced leak.

Figure 7 illustrates the results of the first test conduced by KWA. The LRDP-measured volume and the Wall Volume shown in Figure 7 do not closely trend together during the period from 1500 to 2400 on 17 January 2002. This deviation is due to the thermal expansion and contraction of the fuel at the bottom of the tank that was beneath the bottom of the LRDP system (i.e., the Lift Volume). This source of error was compensated in the AST used for the third-party evaluation by placing the LRDP on the bottom of the tank and shaping the tube [41]. At Fairchild, an estimate of the Lift Volume was computed using the temperature sensor on the DP sensor, which is located inside the sealed container. The TCVR, which is obtained after removing the Wall Volume and the Lift Volume from the LRDP-measured Volume, is also shown. The TCVR is -0.06 gal/h, which results in a Pass, because the TCVR is less than the threshold T.

4.4 Technology Comparison

There are seven other types of systems that can be used to detect leaks in ASTs: (1) in-tank tracer systems, (2) testing service mass-based systems, (3) in-tank mass-based systems, (4) constituent fuel tracer systems, (5) in-tank level and temperature monitoring systems, (6) acoustic systems, and (7) statistical inventory reconciliation systems. The last four types of systems, (4) through (7), do not have the accuracy or reliability for use as either a monthly monitoring system or a precision test system for ASTs. The third type of system can meet the monthly monitoring requirements, but does not have the accuracy or reliability to perform a precision test. Only the first two systems can also be used to meet both the monthly monitoring and precision test requirement, but, as described in Section 5, the cost of test is significantly greater than that of the LRDP.

5.0 Cost Assessment

This section summarizes the cost and cost savings achievable with the LRDP for testing bulk ASTs. This section also compares the cost of the LRDP to other in-tank mass-based systems, both in-tank ATGs and portable testing-service systems, and to external tracer-based systems. The cost advantages of the LRDP are realized because of the extremely high performance of the LRDP, the on-line monitoring capability of the LRDP when permanently installed in a tank, the capability of the system to conduct a short test (less than 24 h), and the low recurring costs associated with routine testing to address regulatory requirements. And as explained below, the cost savings are significant.

5.1 Cost Reporting

Two DEM/VALs of the technology were conducted. The approximate costs of these DEM/VALs are summarized in Table 8. The first DEM/VAL was to install an LRDP system in a 10,000-bbl (420,000-gal) bulk AST at the Fairchild Air Force Base, Spokane, Washington and to conduct a series of tests to demonstrate that accurate leak detection tests could be performed in a fixed-0roof tank with a floating pan. In the second DEM/VAL, a third-party evaluation of the LRDP was performed in a 150,000-bbl (6,470,000-gal) fixed-roof AST at FISC Pearl Harbor, Hawaii, the largest diameter AST owned by the DoD. The same LRDP system was used for both DEM/VALs. The DEM/VAL costs include an initial site visit, installation, checkout, and removal of the equipment, and conduct of the DEM/VAL (data collection, analysis, and briefing of the results). The DEM/VAL at Fairchild AFB required the collection of data over a 4-month period. The DEM/VAL at FISC Pearl Harbor required the collection of data over a 4-month period; the data for the third-party evaluation was collected between 19 June 2003 and 29 August 2003.

Table 8. Summary of the Costs of the Two DEM/VALs of the LRDP System

DEM/VAL	Cost of the DEM/VAL	Cost of the Third-Party Evaluation	Total
Fairchild Air Force Base	$75,000	$20,000	$950,000
FISC Pearl Harbor	$75,000	$25,000	$100,000
Total	**$150,000**	**$45,000**	**$195,000**

5.2 Cost Analysis

The total life-cycle cost of leak detection includes the following items:

- ***Cost of Regulatory Compliance:*** Purchase, installation, and operation of a leak detection system (direct and recurring costs)
- ***Cost Avoidance***
  - ***Fines and Shutdown of Operations:*** Costs associated with fines for not being in compliance and the cost impact on operations and operational readiness. (direct cost)
  - ***Tank Replacement Cost Avoidance:*** Pre-mature replacement of tanks (direct cost)

– ***Remediation/Cleanup Cost Avoidance:*** Clean-up costs due to lack of testing or testing mistakes (direct cost)

- ***Commercialization and Technology Transfer Cost:*** Commercialization of the pre-production system (direct cost)

It is possible to make an estimate of all of these costs, because the performance of the leak detection system is known. The P_D and P_{FA}, which was determined in the third-party evaluation, allow estimates of the cost of testing mistakes, remediation, and tank replacement to be made. The *cost of regulatory compliance* is described below; the costs associated with *cost avoidance* and *commercialization and technology transfer* are described in Section 6.2.

Regulatory compliance will include the costs associated with the purchase, installation, and use of a leak detection system. It is estimated that the DoD owns or operates approximately 4,000 bulk ASTs with capacities greater than 100,000 gal. The life-cycle cost of a leak detection technology is comprised of the elements in Table 9. The Startup costs are fixed costs and

Table 9. Compliance Monitoring Technology Costs for the LRDP on a Per Tank Basis

Direct Environmental Costs				**Recurring or Variable Environmental Costs**			
Startup		**Operation & Maintenance**		**Compliance Testing**		**Testing Mistakes**	
Equipment Cost	$40,000	Equipment Cost	$40,000	Equipment Cost	$40,000	FA Mitigation Remediation	$40,000 $750,000
Activity	**%**	**Activity**	**%**	**Activity**	**%**	**Activity**	**%**
Facility preparation, mobilization	$4,000 (10%)	Labor to operate equipment	$4000 (10%)	Monthly monitoring	$400 (1%)	False alarms (P_{FA} = 1.0%)	$400 (1.0%)
Equipment Design	$4,000 (10%)	Utilities	$800 (2%)	Annual precision testing	$400 (1%)	Missed detections*	$938 (0.125%)
Equipment purchase	$40,000 (100%)	Consumable and supplies	$400 (1%)	Facility shutdown costs for testing	$1,200 (3%)		
Installation	$8,000 (20%)	Equipment maintenance	$2,000 (5%)				
Training of Operators	$2,000 (5%)	Training of operators	$800 (2%)				
Total	**$58,000** **(145%)**	**Total**	**$8,000** **(20%)**	**Total**	**$2,000** **(5%)**	**Total**	**$1,338**

* It is assumed that the P_D = 95% against a TLR = 0.2 gal/h and the number of leaking tanks is 2.5% of the 4,000 bulk ASTs owned by the DoD. While routine testing with the LRDP should decrease the average cost of new remediations, for this calculation, we assumed the average historical remediation cost.

Include the costs associated with the purchase, installation, and operator training. The Operational and Maintenance costs are also fixed, but are small for the LRDP. The recurring costs associated with Compliance Testing and Test Mistakes are also very small, because once the LRDP is permanently installed, a test can be initiated by pressing a start button, and the performance of the LRDP is very high.

In general, it is not the direct costs that control the price of a leak detection system. Rather, the recurring costs of monthly monitoring and annual precision testing tend to control. For poor performing systems with a higher than desired P_{FA}, the cost of testing increases, because

- additional tests with the same system or another system will have to be conducted to distinguish false alarms from leaks,
- site investigation may be required in terms of monitoring wells or uncovering of buried tanks to determine whether or not the tank is actually leaking,
- such false declarations may have to be reported to regulatory authorities with all the ramifications of such a report, and
- the activities required to determine whether or not a failed test is a false alarm will shutdown facility operations until the false alarm can be resolved.

If the P_{FA} is unacceptably too high, operational experience indicates that fuel farm personnel often do not operate or trust the equipment, and thus, leaks may go undetected. This can be very costly because of the remediation costs associated with undetected leaks.

Table 9 summarizes the costs associated with regulatory compliance with the LRDP. A Parts List for the LRDP is presented in Section 6.4 of the final report [1]. The purchase price of an LRDP assumed for this estimate is based on the purchase of 10 in-tank sensor units. Table 9 presents the cost model in terms of a percentage (%) of the equipment purchase price. The costs of false alarms and missed detections are based on an assumed price for additional testing ($500) and an average remediation cost ($750,000 per incident). The average remediation cost is based on 890 remediation jobs performed by the Navy. These two costs are indicated in the table heading. It is assumed that the P_{FA} is 1.0%, and that the probability of a missed detection is $P_{MD} = 1 - P_D = 5\%$ for a target leak rate of 0.2 gal/h. It is further assumed for this computation that 2.5% of all of the bulk ASTs owned by the military are leaking. Because small leaks can be detected with the LRDP, the large average cost of remediation can be greatly reduced (e.g., 25% of the average cost); for this calculation, however, it is assumed that the cost of remediation is equal to the average cost.

An important cost is the cost of shutdown associated with testing and testing mistakes (false alarm investigations). Since the military is not selling fuel commercially, any short-term or permanent shutdown of fueling operations is difficult to quantify in terms of dollars. However, it is unacceptable to shutdown military operations, or to seriously impact operational readiness. An estimate of $40,000 for a False Alarm mitigation was used in Table 9, resulting in a $400 per tank cost at a P_{FA} of 1.0%. The total cost per tank is $69,340. A cost comparison of the LRDP and tracer and other mass-measurement systems is given in Section 5.3.

5.3 Cost Comparison

The LRDP has several significant cost advantages over other technologies. An estimate of the cost savings realized by the LRDP over three other methodologies is shown in Tables 10 - 12. Method 1 represents an in-tank tracer method with monthly monitoring. It is well documented that this method has a high recurring cost for Compliance Testing. Method 1 assumes that a tracer must be added to the tank; no cost estimate is provided for tracer methods that use constituents in the fuel as tracers, because their performance has been found to be unacceptable. Method 2 is an in-tank, mass-based method that is assumed to have the capability to meet both the annual precision test and the monthly monitoring requirements, but only as a testing service. Method 3 is an in-tank mass-based, automatic tank gauge (ATG) method that only has the capability to meet the monthly monitoring requirements. It is assumed that another method, like the LRDP or the in-tank tracer method is used to meet the annual precision test. No other permanently installed in-tank, mass-based system besides the LRDP has the capability to meet an annual precision test performance standard (at 0.2 gal/h). No specific commercial methods are identified by brand name here. The cost savings achieved with the LRDP over the in-tank tracer method (Method 1) is mainly due to the very much smaller recurring cost of testing with the LRDP than with the tracer method. The main cost savings achieved with the LRDP over other in-tank mass-based methods that can only meet the annual precision and monthly monitoring requirement as a testing service (Method 2) is the large recurring monthly cost of the service. The main cost savings achieved with the LRDP over other in-tank mass-based ATG methods Method 3) is due to the fact that the LRDP can be used to conduct an annual precision test, while the other in-tank systems cannot. The best way to interpret the tables is to examine the relative cost savings between the LRDP and the other methods. The calculation uses the fixed Start-up costs and the recurring Compliance Testing costs from Table 9 for the LRDP.

The cost comparison calculation is done as follows. First, it was assumed that the Startup and O&M costs are the same for all permanently installed methods. Established price lists for bulk leak detection systems are not generally available or extremely meaningful, because most product sales or testing jobs are performed under a unique contract bid. This computation assumes $40,000, which is higher than anticipated for the LRDP and is lower than typically charged for Method 3. This estimate includes the one-time purchase of the equipment for $40,000 (same as for the LRDP), as well as the same operation and maintenance costs, and the same cost of testing and testing mistakes. While the equipment, operation, and maintenance costs are assumed to be the same for the calculation, a one-time purchase of equipment can be as high as $75,000 for other mass-based systems, and the other mass-based methods typically have a higher probability of testing mistakes than the LRDP. Second, a mobilization charge was added for each site visit to conduct a test at a facility for those methods that are based on a testing service. However, the mobilization charge used for the monthly monitoring tests was reduced, as appropriate, over that of the annual visit. Also, the mobilization was the same for each facility, regardless of the number of tanks tested at that facility. Third, the real cost savings of the testing tends to be controlled by the recurring cost of testing (i.e., experienced with a monthly testing service), or the cost of additional testing because of the lack of capability of the method to satisfy *both* the monthly monitoring and the annual precision test. The estimate assumes that 12 monthly tests and one annual precision at 0.2 gal/h are conducted each year. Fourth, there are significant cost savings associated with cost avoidance and remediation/cleanup when accurate and reliable leak detection is being performed. It is safe to say that the DoD would realize significant cost savings (many hundreds of millions of dollar) if any leak detection system was installed and used. However, if a reliable and accurate leak detection system is used, like the LRDP, these savings could be a factor of 2 to 5 times greater. The cost savings that could be realized by cost avoidance and lower remediation costs are *not* included in this calculation. Fifth, this cost comparison does not include the costs of Testing Mistakes. The number of tests to be conducted each year will be increased (1) if the leak detection system is susceptible to false alarms, or (2) if tests need to be repeated, because they are too long and must be prematurely terminated or because they interfere with operations. Again, the LRDP has a real advantage in terms of performance, but this advantage is not included in this comparison.

Table 10 summarizes the cost of the testing a *100-ft-diameter AST* with each of the methods listed for the *first* AST tested at a bulk storage facility and for *additional* ASTs tested at that facility. Table 10 summarizes, as appropriate, the initial purchase and installation of the leak detection system, the cost of performing 12 monthly tests, and the cost of performing an annual precision test. It is assumed that the first test and the mobilization for the first AST tested at a facility, which includes the initial site preparation and/or annual maintenance checkout, costs significantly more than the remaining 11 monthly monitoring tests. The mobilization is applied only to the facility and is the same regardless of the number of ASTs tested at that facility. However, it is also assumed that the mobilization for the monthly tests is reduced over that charged for the first test at a facility. It is also assumed that the first test on any AST tested at that facility may have a different (higher) price than the remaining 11 monthly tests.

Table 10. Comparison of the Cost of Testing in Dollars ($) with Monthly Monitoring and an Annual Precision Test for the First and Additional Bulk ASTs at a Single Facility or Fuel Farm for the First Year

	Purchase of System	**Monthly Monitoring**			**Precision Test**	**Total**	**Total**
	Initial Purchase for One UST System	**Cost of 1st Test on Any AST Tested & One Time Facility Mobilization**	**Cost of Each Monthly Test & Mobilization on 1st AST at a Facility**	**Cost of Additional ASTs Tested at a Facility w/o Mobilization**	**Annual Cost of a Precision Test**	**Annual Cost of Compliance for Year 1 for the 1st AST at a Facility**	**Annual Cost of Compliance for Year 1 for Additional ASTs at a Facility**
Method 1 (In-tank Tracer Testing Service/Installation)	0	6,200 & 8,000	3,750 & 4,000	3,750 & 0		99,450	47,450
Method 2 (In-tank Testing Service)	0		8,000 & 8,000	8,000 & 5,000	16,000	159,000	96,000
Method 3 (In-tank ATG)	40,000	480 & 0	480 & 0	480 & 0		61,760	61,760
LRDP	40,000	480 & 0	480 & 0	480 & 0		45,760	45,760
Method 1/LRDP						2.2	1.0
Method 2/LRDP						3.5	2.1
Method 3/LRDP						1.3	1.3

Table 11 summarizes the total cost of meeting the regulatory requirements for a single bulk AST for all four methods. For comparison, the ratio of the cost of each method relative to the LRDP is given in the tables. Clearly, the recurring cost of the monthly tests associated with Methods 1 and 2 dominate the cost of testing. Table 12 summarizes the cost for a fuel farm containing six bulk ASTs. A factor of two cost savings are observed for the two testing-service methods over that of using these methods for testing only one AST at a facility. These cost savings are realized because only one mobilization cost is charged when more than one tank or test is conducted at the same facility. However, the total cost of these methods is still significantly higher than the LRDP, and do not change much more even if 10 or 20 ASTs are tested at a facility. The total cost savings throughout DoD would be significantly higher if all 4,000 ASTs are included in the estimate.

Table 11. Comparison of the Cost of Testing in Dollars ($) with Monthly Monitoring and an Annual Precision Test for the First Bulk AST at a Facility Over 1, 3, 5 and 10 Years

Testing Method	Total Cost of Compliance for			
	First Year	Three Years	Five Years	Ten Years
Method 1 (In-tank Tracer)	99,450	298,350	497,250	994,500
Method 2 (In-tank Testing Service)	192,000	576,000	960,000	1,920,000
Method 3 (In-tank ATG)	61,760	105,280	148,800	257,600
LRDP	45,760	57,280	68,800	97,600
Method 1/LRDP	1.9	3.1	3.9	5.0
Method 2/LRDP	3.5	8.3	11.6	16.3
Method 3/LRDP	4.2	10.1	14.0	19.7

As presented in Table 11, over a 10-year period, the cost of the two methods (Methods 1 and 2) for testing an AST at a facility requiring monthly tank preparations or monthly visits, when compared to the LRDP, is a factor of 10 to 20 higher than the LRDP when only one AST is tested. When multiple ASTs are tested, as presented in Table 12 for a six-AST facility, the cost saving is a factor of 5 to 10 higher than the LRDP. The LRDP has at least a 3 to 1 advantage over the lower performing in-tank mass-based ATG (Method 3).

The savings of the LRDP compared to Methods 1 and 2 would result in a payback period of less than one year, and the savings compared to Method 3 would result in a payback period of approximately three years, even without including the savings due to fewer tank replacements and lower remediation costs and the inconvenience of having a testing service come in annually.

Table 12. Comparison of the Cost of Testing in Dollars ($) with Monthly Monitoring and an Annual Precision Test for Six Bulk ASTs at a Facility Over 1, 3, 5 and 10 Years

Testing Method	Total Cost of Compliance for			
	First Year	Three Years	Five Years	Ten Years
Method 1 (In-tank Tracer)	336,700	1,010,100	1,683,500	3,367,000
Method 2 (In-tank Testing Service)	672,000	2,016,000	3,360,000	6,720,000
Method 3 (In-tank ATG)	370,560	631,680	892,800	1,545,600
LRDP	274,560	343,680	412,800	585,600
Method 1/LRDP	1.9	3.1	3.9	5.0
Method 2/LRDP	2.3	5.6	7.7	10.9
Method 3/LRDP	2.4	5.9	8.1	11.5

6. Technology Implementation

6.1 Cost Observations

DoD owns more than 4,000 ASTs of varying capacities. While the leak detection requirements for ASTs were deferred in EPA's UST regulation issued on 22 September 1988, many of the states have or are in the process of requiring testing of such tanks. Although Federal regulations have deferred ASTs from monthly monitoring and/or annual precision testing, state regulators are now imposing stringent leak-detection requirements. This presents a unique problem for the DoD, because it owns and operates a large number of bulk ASTs, and no online system currently exists that can perform monthly monitoring tests and an annual precision test. The requirement for testing may cost many tens to hundreds of millions of dollars, depending on the testing approach used. In comparison to other technologies, the LRDP can realize significant cost savings for the DoD. The average cost of the LRDP is a factor of 3 to 11 times less than competing technologies.

The cost of compliance and a comparison of the costs between the LRDP and other methods were described in Section 5. A discussion of the additional cost savings that can be realized due to cost avoidance and commercialization/technology transfer is presented in Sections 6.1.1 and 6.1.2.

6.1.1 Cost Avoidance

The magnitude of the cost savings that can be realized by minimizing testing mistakes, managing tank replacement efforts and minimizing remediation/clean-up efforts through early detection of a release is a direct function of the use and performance of the leak detection system. If equipment is used frequently and the performance is high (i.e., the probabilities of false alarm and missed detection are low), then the need to routinely replace tanks can be minimized. They can continue to be used with confidence that they are not leaking, and if a leak develops, that it will be quickly detected. This reduces the volume of fuel released into the ground and the scope and cost of the cleanup. The high performance of the LRDP means that the number of false alarms and missed detections will be much smaller than other technologies. Furthermore, the high performance of the LRDP allows the probability of false alarm of the system to be set to a very low level without sacrificing the detection of small leaks. The other mass-based systems and some tracer-based approaches do not have the performance to operate with a low probability of false alarm. In addition, other mass-based methods must operate at a higher target leak rate. The total cost savings that can be realized by implementing a reliable leak detection program can be $500 million to $1 billion dollars. These cost savings are described below.

Fines and Shutdown of Operations. The cost of testing more than offsets the cost of the fines that may be levied if the tanks are not tested within the specified regulatory guidelines and are out of compliance. Fines may be $25,000 per day per facility, or more. Ultimately, if the bulk ASTs are not in compliance, fuel operations can be shut down. Since the military is not selling fuel, any permanent or short-term shutdown of fueling operations is difficult to quantify in terms of dollars. However, it is unacceptable to shutdown military operations, or to seriously impact operational readiness. Because the LRDP has the performance to perform both the monthly monitoring and the annual precision test, it is the most cost effective way to be in compliance. Because in many instances, an LRDP test can be performed in 20 h rather than the 48 or 72 h required by other methods, the impact on shutdown is significant.

Tank Replacement Cost Avoidance. Most bulk ASTs are expensive to replace; the costs per tank can be many millions to tens of millions of dollars. Replacement costs can be minimized, avoided, or delayed by using accurate and reliable leak detection. The use of accurate and reliable leak detection can justifiably and safely avoid premature replacement of tanks. The cost savings associated with the use of leak detection is very large. If we assume that the cost of replacement is $5 per gallon of stored fuel, it would cost approximately $10,000,000 to replace a 70-ft-diameter AST. The cost of adding a double bottom and interstitial leak detection might be $500,000 as compared to adding an LRDP at $70,000. Regardless, leak detection is an inexpensive alternative to tank replacement.

Remediation/Cleanup Cost Avoidance. The cost of remediation and cleanup are by far the largest costs associated with leaking tanks and clean-up cost avoidance can be the most significant cost savings realized with the purchase, installation and use of reliable leak detection. It is difficult to estimate the portion of the costs associated with clean-up that can be avoided, but it is significant. The Navy has 659 future LUFT sites to clean up and has estimated that the total cost will be $890,000,000. Early detection of leaks can significantly reduce the total cost of cleanup because the concentration and spatial extent of the plume is smaller than it would be if the leak was not detected early.

6.1.2 Commercialization and Technology Transfer

The costs associated with technology transfer and commercialization are relatively low for the LRDP, because the third-party evaluation has already been completed. At the present time, the NWGLDE, which lists properly evaluated leak detection systems for USTs, is not listing leak detection systems for ASTs. This may change in the future, and the LRDP has been evaluated in accordance with the NWGLDE test procedures. One company, Vista Research, Inc., has already commercialized the pre-production system.

6.2 Performance Observations

All of the performance objectives of this program were met. The LRDP was successfully demonstrated in two DEM/VALs. The evaluated performance obtained in the third-party evaluation during the DEM/VAL at FISC Pearl Harbor is sufficient to address all of the regulatory requirements for DoD's bulk ASTs, because it meets the regulatory requirements for bulk USTs. The results of the DEM/VAL on the fixed-roof tank at the Fairchild Air Force Base indicates that the system can be used to test ASTs with floating pans.

6.3 Scale-up

The DEM/VALs were all conducted on full-scale, operational aboveground storage tanks. The DEM/VALs were conducted on one, if not the largest diameter AST owned by DoD. The performance of the LRDP in other tanks scales with tank diameter (or equivalently, the product surface area of the fuel in the tank). As the tank diameter decreases, the performance improves and smaller leak rates can be detected. Based on the third party evaluation, the LRDP can be used to test tanks with capacities as small as 50,000 gal and with diameters as large as 260 ft, which includes all of the ASTs owned by DoD, and all but a few of the ASTs that exist in the petroleum industry.

6.4 Other Significant Observations

All tank operations must cease during a test; no fuel transfers in or out of the tank are allowed. This temporary shutdown of the tank is minimized by the LRDP in comparison to other in-tank leak detection systems, because the duration of the test is shorter than the other methods. The LRDP can meet the monitoring and precision regulatory requirements in a 20-h test. The other technologies typically require 48 to 72 h, and other than the LRDP, none of the permanently mounted in-tank systems have sufficient performance to perform a precision test.

6.5 Lessons Learned

In order to conduct a leak detection test with this technology, the tank must be isolated from the piping associated with the tank. Thus, it is important that all valves at the tank be completely sealed before a test is initiated. This is particularly important when conducting a precision test at 0.2 gal/h. Many of the valves at DoD facilities are double-block and bleed valves, which allow a visual check of the seal and a measurement of the flow across the valve if it does not seal. The monthly monitoring standards are sufficiently large in comparison to the performance of the LRDP that small valve leaks can be tolerated during a test without impacting the results. No waiting period is required for the conduct of a leak detection test with a mass-based system like the LRDP.

6.6 End-User Issues

The LRDP is ready for commercialization and has been evaluated for performance by a third party. Vista Research, Inc., has commercialized the LRDP and is now offering products and services based on the LRDP implemented using a PLC. Product description and product specification sheets are available (an Appendix of the final report [1]). Immediate commercialization of this technology has been possible, because fuel terminal operators were involved during the demonstrations and the bulk storage tank facilities have a real need to address. Some limited sales of the LRDP have already occurred. For example, the LRDP has been used to test an AST at Point Loma and a chemical tank (containing sodium hydroxide) at an industrial facility.

At the request of NFESC, during this ESTCP project, a workshop was conducted by the Environmental Technology Evaluation Center (EvTEC) of the Civil Engineering Research Foundation (CERF) to introduce the technology and to describe the advantages of the system for regulatory compliance [10]. Technical experts and representatives from the petroleum industry, the Defense Energy Support Center (DESC), and the U. S. Air Force, Army, and Navy were present.

6.7 Approach to Regulatory Compliance and Acceptance

At the present time, AST are not strongly regulated and regulatory standards have not been established. It is clear from public and private forums that many states are developing such regulations or regulatory guidelines. SPCC plans and API 653 inspections encourage leak detection but stop short of requiring it. However, the SPCC encourages leak detection testing by allowing an increased interval between inspections. Also, leak detection has been found to be useful in verifying that a tank is leak free before it is brought back into service after an API 653 inspection. As a consequence, the evaluation was conducted and the results of the evaluation were reported to meet the two practical regulatory guidelines for using in-tank mass-based measurements in California for bulk USTs, which were developed and recommended by NFESC and Vista Research (Options 7 and 10).

It was assumed that the regulatory requirements for ASTs would be similar and no more stringent than those for bulk USTs [14]. Option 7 requires monthly monitoring tests with a system capable of detecting a leak between 1.0 and 2.0 gal/h with a $P_D \geq 95\%$ and a $P_{FA} \leq 5\%$, and a semi-annual precision test with a method capable of detecting a leak of 0.2 gal/h with the same P_D and P_{FA} as for the monthly monitoring test. Option 10 is similar to Option 7, except the monthly monitoring criteria is 0.3 to 1.0 gal/h, and the precision test need only be conducted annually. While the precision test requirement of 0.2 gal/h is stringent, it is achievable by the LRDP and for many tanks with only a single test. The monthly monitoring requirements of 0.3 to 1.0 gal/h or 1.0 to 2.0 gal/h are operationally practical and easily met by the LRDP.

The approach to regulatory requirement depends on the size of the tank to be tested as was discussed in Section 4. The main recommendation is to operate the system such that the regulatory requirements can be met with the lowest probability of false alarm. Given the choice, the monthly monitoring should be addressed using the largest target leak rate as possible less than 2.0 gal/h. This minimizes any minor system problems that might otherwise interfere with a test (i.e., a small flow across a valve).

7.0 References

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8.0 Points of Contact

The points of contact for this project are presented in Table 13.

Table 13. Points of Contact

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